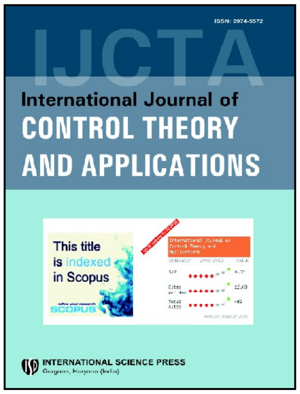

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Mitigation of Current Harmonics Based on DE Technique

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Abstract: Objectives: Current harmonics are some of the major power quality disturbances mainly generated due to expansion of nonlinear loads. Mitigation of current harmonics is done based on DE technique.

Method: This thesis presents a novel approach to diminish the current harmonics. PQ theory is utilized as a control scheme to produce the reference currents. These reference currents are converted into gating pulses with the support of Hysteresis band current controller. This control strategy injects reverse harmonics and cancel out the harmonics in the distribution line.

Findings: Due to the application of non-linear load there is a distortion in current wave form. The THD of source current in the distribution line connected to non-linear load from FFT analysis is very high so in order to reduce PQ theory with PI controller is used . It is clear that the amount of total harmonic distortion is less when compared to distribution line connected to non-linear load.

Improvement: Further, PI controller in PQ theory are optimized with DE technique to improve THD. The simulations were verified in MATLAB 7.10/SIMULINK software and results were compared with PI, PI-DE technique.

Keywords: Current Harmonics, Instantaneous active and reactive power (p-q) theory, Shunt Active Power Filter (SHAF), Differential Evolution (DE), Total Harmonic Distortion (THD).

1. INTRODUCTION

In modern times, with the expansion of power electronic devices the control and conversion of power becomes a piece of cake. But by using these power electronic devices power quality becomes a prominent issue. Power quality is continually described as the electrical network or the grid potential to afford a virtuous and secure power supply. In other words, power quality ideally develops a faultless power supply that is always available, has a pure noise-free sinusoidal wave shape, and is forever with in voltage and frequency tolerances. But by using these power electronic devices power quality becomes an renowned issue. Current harmonics is main cause for humiliating power quality which have unfavourable economic pressure on utilities and customers. Power quality problems are more sensitive to the quality of the electrical power supply. Power quality problems are harmful for both the power system and customers. Because of non-linear loads the supply current and as well as supply voltage are non-sinusoidal wave forms. These complications of harmonics may be modified by the usage of filters. Filters are generally classified as Passive filters and Active Filters. Passive filters have several disadvantages like parallel and series resonance, fixed compensation characteristics. The active power filters are proved to be very efficient in the lessening of the system harmonics [2].

Attractive attributes of active filters include the fact that they are tiny in size as well as their ability to attenuate the harmonic current in power system through injection of equal and opposite compensatory current. Active filters are again categorized as series-active, shunt-active, as well as hybrid-active filters [4].

Principally shunt active power filter work as injecting current source to the harmonic components produced by the load excluding phase shifted by 1800 and as well as it remunerate load current harmonics by introducing equal but reverse harmonic compensating current [13]. Series active filters work as a harmonic isolator and mostly as a voltage regulator among the nonlinear load and as well as the benefit source. The series active filter generates a voltage component in series with the supply voltage and eliminates harmonic components in voltage waveforms and for that reason it can be regarded as a controlled voltage source, compensating voltage sags and swells on the load side. mostly shunt active power filter are more effectual and low cost compared to series active power filters because most of the nonlinear loads create current harmonics. A hybrid filter is a mixture of active power filter and passive power filter which reduces filter rating and improves the resonance characteristics.

SHAF is used for mitigation of current harmonics. It is an inverter for generating compensatory current which eradicate the harmonic component created by nonlinear load. [3] There are several control strategies have been developed recently but this paper mainly focused on PQ theory. This theory has its basis on a group of instantaneous powers determined in the time domain as well as utilizes the park’s transform. The theory is effective as well as flexible to design controllers for power conditioner on the basis of power electronic device and it is used to design controllers for active filters. The traditional controller like PI need accurate linear mathematical models of the system that are hard to get under variable variation, non-linearity, or load disturbances. In PQ theory PI controller is optimized with DE technique. DE is a method that optimizes an issue through iterative attempts to develop a potential solution considering a particular measure of quality. DE optimization technique is utilized as a tool for minimizing the THD. In this paper relative comparisons has been made between PI-controller Optimized with and DE technique and the simulation results were plotted.

This thesis is structured thus: Section I organizes the introduction and Section II handles PQ theory, Section III handles details of DE technique, Section IV yields simulation results and lastly section V gives all final remark.

2. INSTANTANEOUS REAL AND REACTIVE POWER THEORY (P-Q)

The active power filter currents are attained from the instantaneous active powers and as well as reactive powers p & q of nonlinear loads [1]. Conversion of the phase voltages as well as the load currents in to the perpendicular coordinates are set in equation 1 & 2.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{2}$$

The instantaneous active as well as reactive power in α-β-0 co-ordinates are computed with the subsequent formulae [6].

$p_0 = v_0, i_0$

$p = v_{\alpha*} i_\alpha + v_{\beta*} i_\beta$

$q = v_{\alpha*} i_\beta - v_{\beta*} i_\alpha$

where,

p represents an instantaneous real power

q represents an instantaneous reactive power

p_0 represent instantaneous zero sequence power

Here, instantaneous real as well as imaginary powers are $V_\alpha I_\alpha$ & $V_\beta I_\beta$. As they are products of instantaneous voltages as well as currents in the identical axis [9], In 3-Φ circuits, instantaneous real power is p; with unit as watt. In disparity $V_\alpha I_\beta$ & $V_\beta I_\alpha$ are not instantaneous powers. As these are products of instantaneous voltages as well as currents in 2 orthogonal axes. The value of q is instantaneous reactive power; unit as imaginary volt-ampere. q does not have traditional electric units such as watt. The foremost aim of the p-q theory is to assemble the source to distribute the constant active power required by the load. Simultaneously, the source should not send any 0 sequence active power. The reference source current in the α-β-0 co-ordinates is thus:

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{\sqrt{v_\alpha^2 + v_\beta^2}} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \tag{3}$$

As, the 0-sequence current needs compensation reference compensation current in the zero co-ordinate is i_0 it sel

$$i_0 = i_{c0}^* \tag{4}$$

The inverse transformation of Equation (2) is applied to achieve the reference compensation current in the a,b,c coordinates.

$$\begin{bmatrix} i^*_a \\ i^*_b \\ i^*_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i^*_{c0} \\ i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} \tag{5}$$

Here *ia*, ib*, ic** are the instantaneous three-phase current references. The computations offered as of yet are synthesizes as well as corresponded to shunt active filter control scheme for constant instantaneous supply power [7, 8].

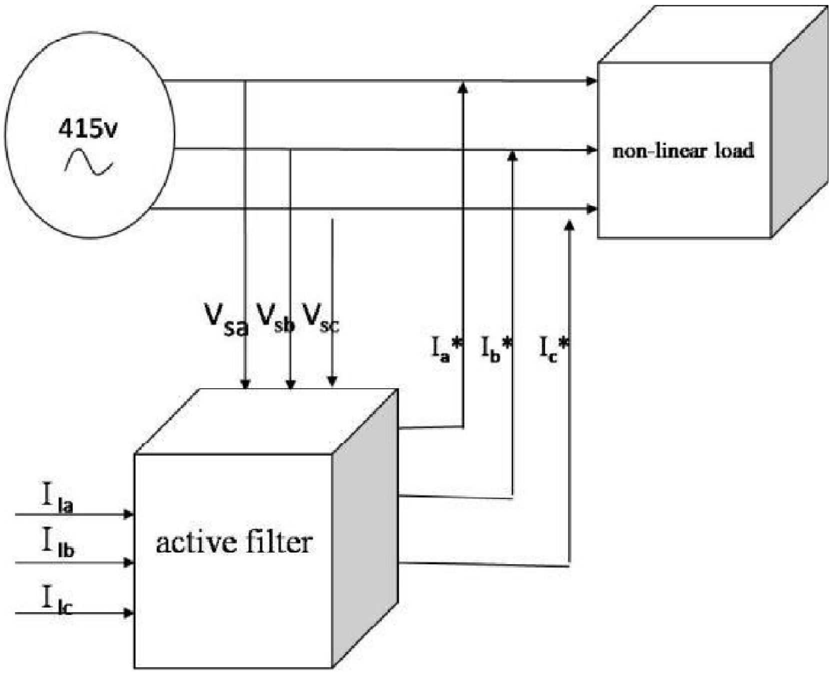

Figure 1: Basic Structure of Shunt Active power filter

SHAF is termed as a voltage source inverter (VSI), it controls current source through pulse width modulation (PWM) signals [5]. Here, SHAF is connected in parallel with the nonlinear load and it is given in Figure1. Harmonic current compensation may be attained through injection of equal as well as opposite harmonic current component at the point of connections, to remove the disturbance as well as increasing power quality.

It is also possible to reorganize power and to keep the structure balance In case of non-linear loads and 3-Φ unbalanced source. The active power filter [2] comprises main circuit reference current calculating circuit, driving circuit and current tracking circuit. In this theory i used PI controller. Thus reference currents are converted in to gating pulses using HBCC and gating pulses are given to inverter. By using 3-Φ inverter reverse harmonics are injected backing to the line. As a result, harmonics are cancelled out each other the sinusoidal wave form appears. Then we measure THD. The main objective is to minimize THD. Additionally in PQ theory, PI controller is optimized with DE technique.

3. PROPOSED METHOD

DE refers to a vector population based on stochastic optimization technique and it is suggested in 1995 by Rainer storn & Kenneth price. It is similar to genetic algorithm (GA) and the technique is capable of optimizing objective function that is a function of discrete parameter. It has became very well-organized method because of its abundant attributes like lesser control variables, easier programming, as well as parallel nature, simplistic structure, easier usage, convergence speed as well as resilience are some of the advantages of DE technique. [10,11,12] Applications of DE technique include optimization of fermentation of alcohol, Designing digital filter, optimizing schemes for checkers, maximizing profit. DE handles both linear as well as nonlinear objective functions, single as well as multi-objective.

In this proposed method the main objective is to minimize THD. The PI controller in SAPF theory are optimized with DE by taking K_p and K_I as optimized variables and the fitness function is taken as THD

The following is the procedure to implement DE technique

1. Initialization: Foremost initialize the population size, decision variables, fitness function

$$X_i^0 = X_{min} + \rho_i(X_{max} - X_{min}),\ i = 1,........N_p \quad (6)$$

Where ρi Є [0,1] is a random number. The initial procedure N_p individuals of X_i^0 randomly

2. Mutation: The main endeavor of mutation process is to produce mutant vector. A mutant vector is generated based on the current individual X_i^G as follows:

$$Y_i^{G+1} = X_i^G + F((X_{r1}^G - X_{r2}^G) + (X_{r3}^G - X_{r4})) \quad (7)$$

Where i =1,2,3.......N_p; r_1,r_2,r_3 and r_4 arbitrarily chosen and are dissimilar;

F Є [0,2] Here, F is the mutation rate and it is determined empirically.

3. The Cross Over: Cross over is a process of mixing parent vector with mutant vector. The parent vector is combined with the mutant vector to produce trial vector (off spring).

$$\begin{cases} X_{hi}^G, & \text{if a random number} > C_r \\ Y_i^{G+1} = Y_{hi}^{G+1}, & \text{otherwise} \end{cases} \quad (8)$$

where, i =1,2,3........N_p; h= 1,2.........n_c; wherein n_c represents the dimension of decision parameters; Y_i^{G+1}, X_i^G are mutant and parent vectors.

C_r Є [0,1] Here, C_r is the cross over constant, which controls diversity of population.

4. The Selection: In this segment, the parent vector is substituted by its offspring. If the fitness of the off spring is more than that of the parent is engaged for the next generation.

$X_{hi}^{G+1} = \text{argmin}\{ F(X_i^G),F(Y_i^G),F(Y_i^{G+1})\}$

$X_b^{G+1} = \text{argmin}\{F(X_i^{G+1})\}$

where argmin is the argument of the minimum and X_b^{G+1} is the best individual. Fig. 2 shows basic optimizing of k_p and k_i in PI controller with differential evolution technique.

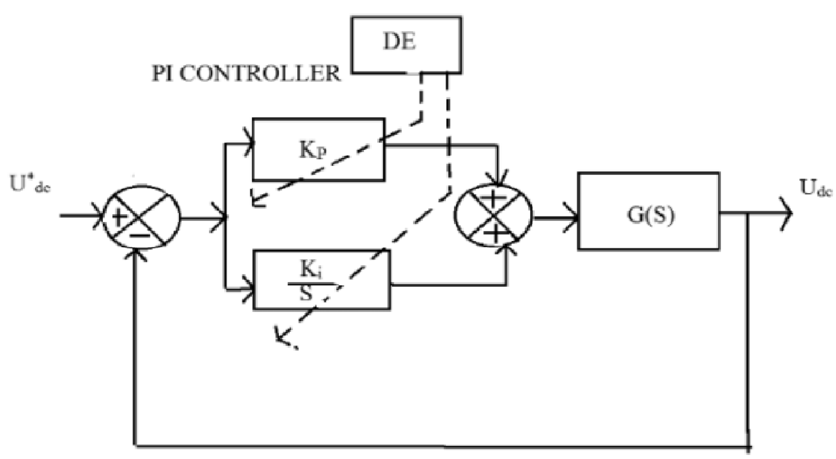

Figure 2: Basic Optimizing of kp and ki in PI with DE technique

4. SIMULATION RESULTS

The simulation results are available in this section. The outcomes are verified through MATLAB SIMULINK software.

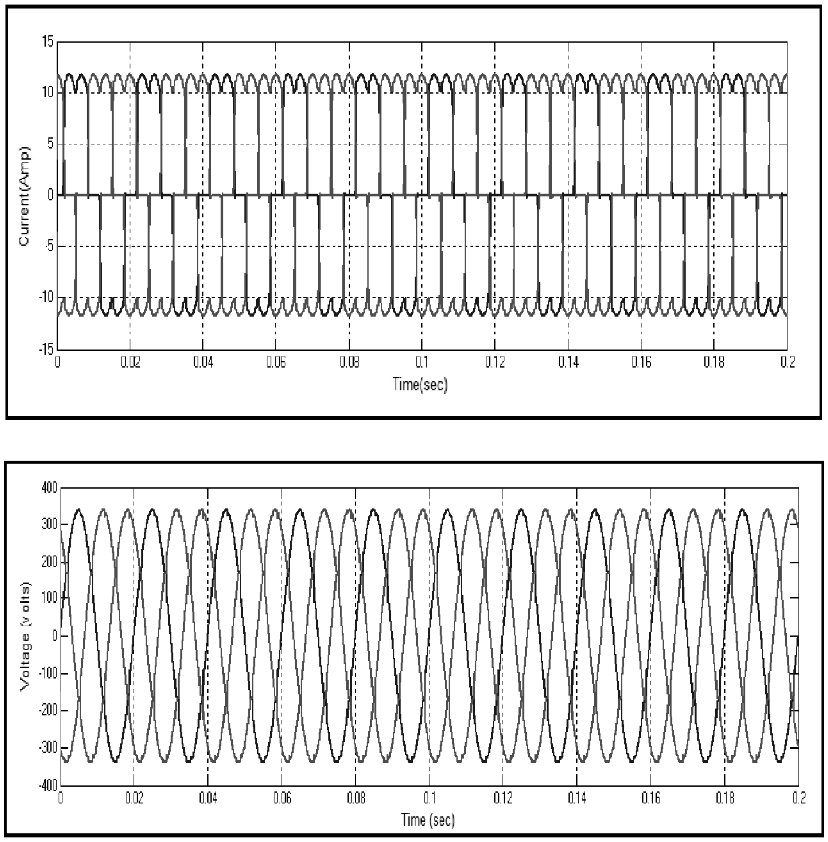

Figure 3: Source current and voltage wave forms before SHAF

Here, there is a distortion in current wave form because of nonlinear load application. Where, current harmonics are created with the help of non-linear load. Disadvantages of current harmonics are heating of equipment, power factor deviation etc.., In simulation diode bridge rectifier with RL load is utilized as a nonlinear load so, as a result current harmonics occur in the line as shown in Fig 3.

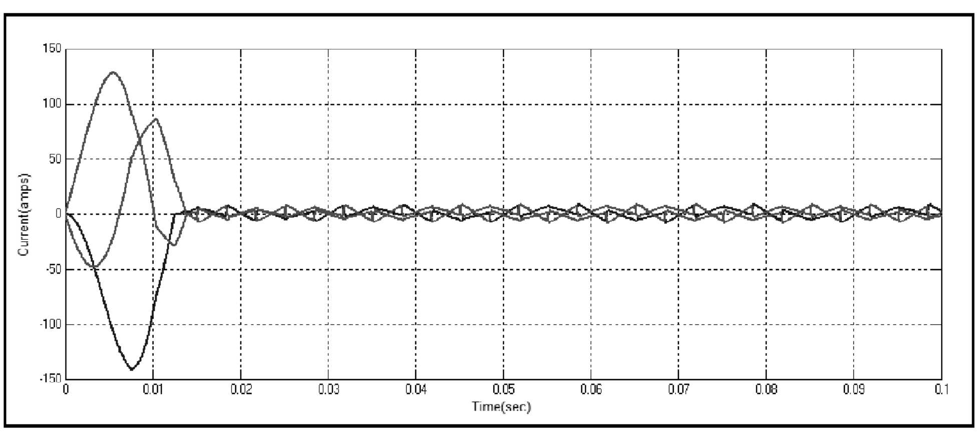

Figure 4: Compensating currents using PQ theory

The SHAF injects reverse harmonics into the line and cancel out the harmonic currents available in the source current and helps to maintain the source current harmonics free. These reverse harmonics are generated with the help of PQ control strategy using HBCC as given in Fig. 4.

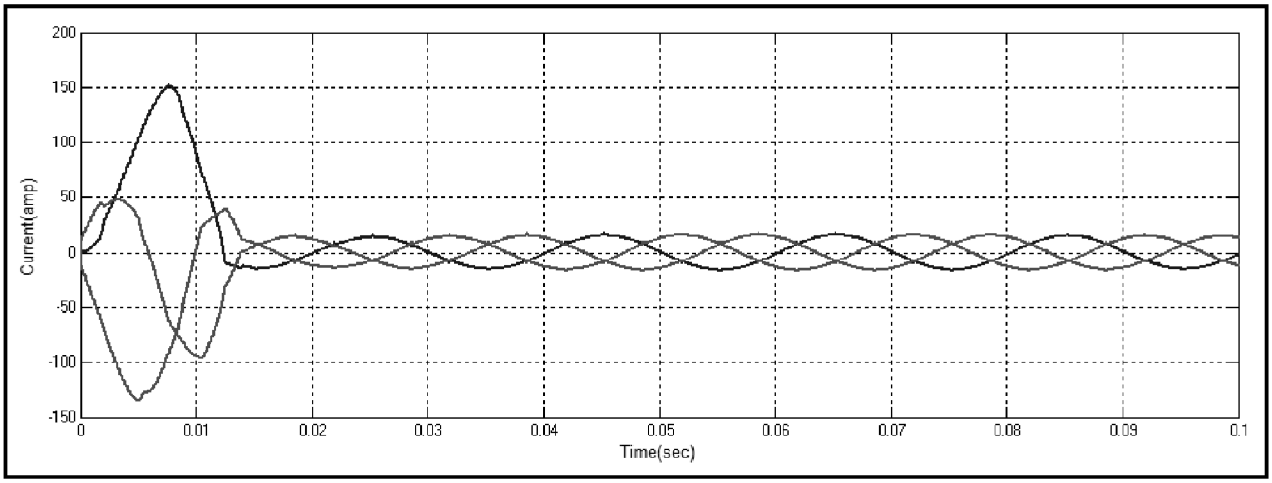

Figure 5: Source current waveform after application of SAPF

Fig. 5 displays the source current waveform after the application of SHAF. In order to get effective T.H.D there is a need to get optimum values of K_p and K_I. PI controller is optimized with DE technique to discover optimum values of K_p and K_I. This technique is used as a tool for minimizing the THD with DE technique. This technique is used asa tool for minimizing the THD.

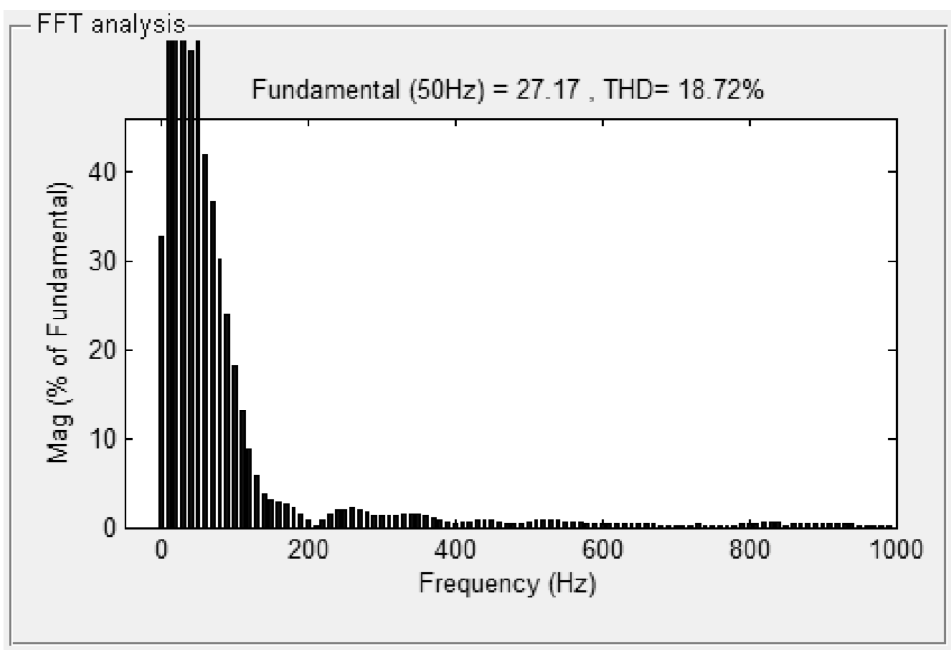

Figure 6: THD of source current in the distribution line from FFT analysis

Above fig. 6 reveal the THD of source current in the distribution line connected to non-linear load from FFT analysis. The total THD obtained is 18.72%.

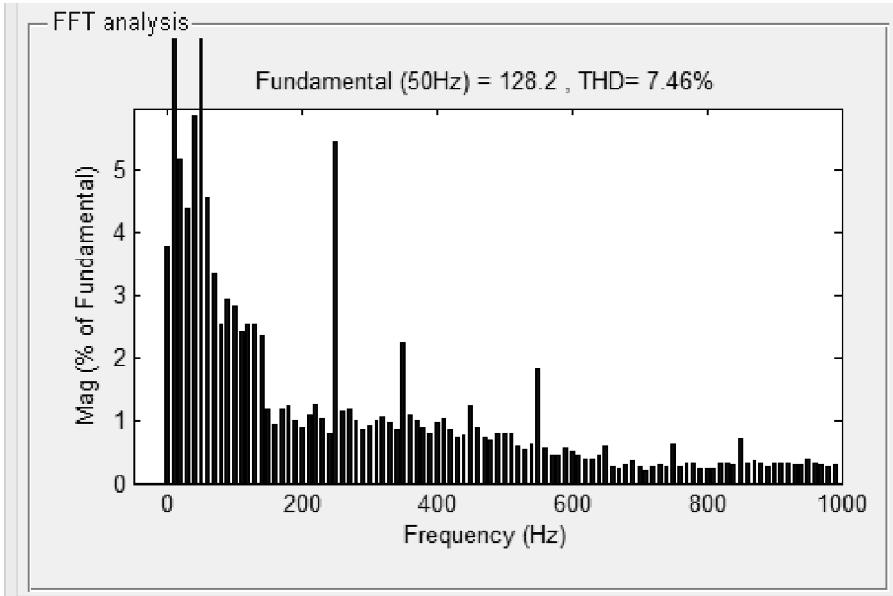

Figure 7: THD of source current from FFT analysis with PQ theory using PI controller

Above fig. 7 reveal the THD of source current using PQ theory with PI controller through FFT analysis. It is clear that the amount of total harmonic distortion is 7.46%.

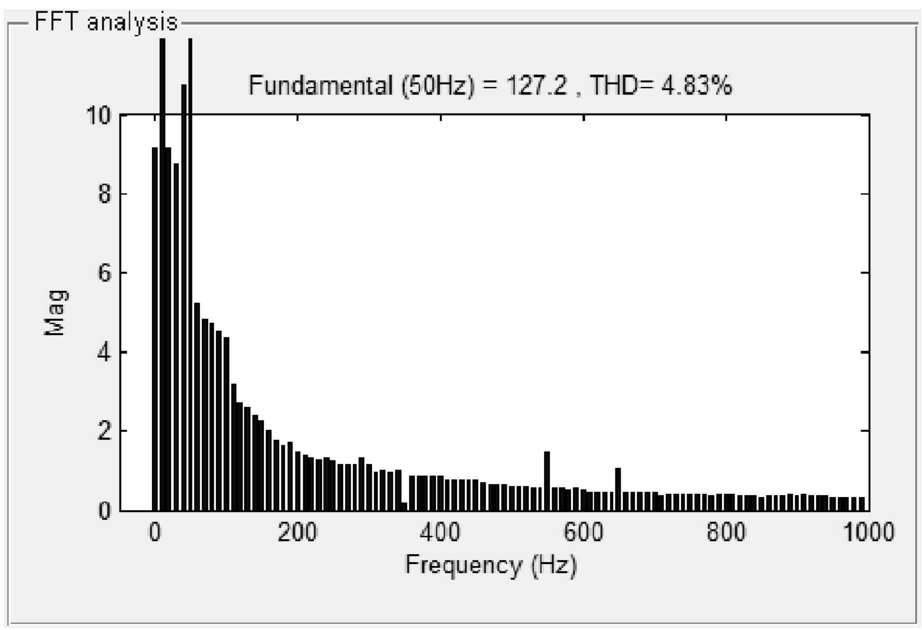

Figure 8: THD of source current from FFT analysis with PQ-DE

Fig. 8 reveal the THD of source current using PQ-DE technique by FFT analysis. The amount of THD is 4.83%.

From Fig. 6, Fig. 7, and Fig. 8 clearly reveals that the amount of THD obtained is high in basic distribution line connected to non-linear load when compared to PQ theory with PI controller and PQ-DE technique. The proposed method i.e, PQ theory with DE technique shows very less value of THD i.e, 4.83% compared to PQ theory using PI controller and basic distribution line with nonlinear load. The outcomes are tabulated in table II.

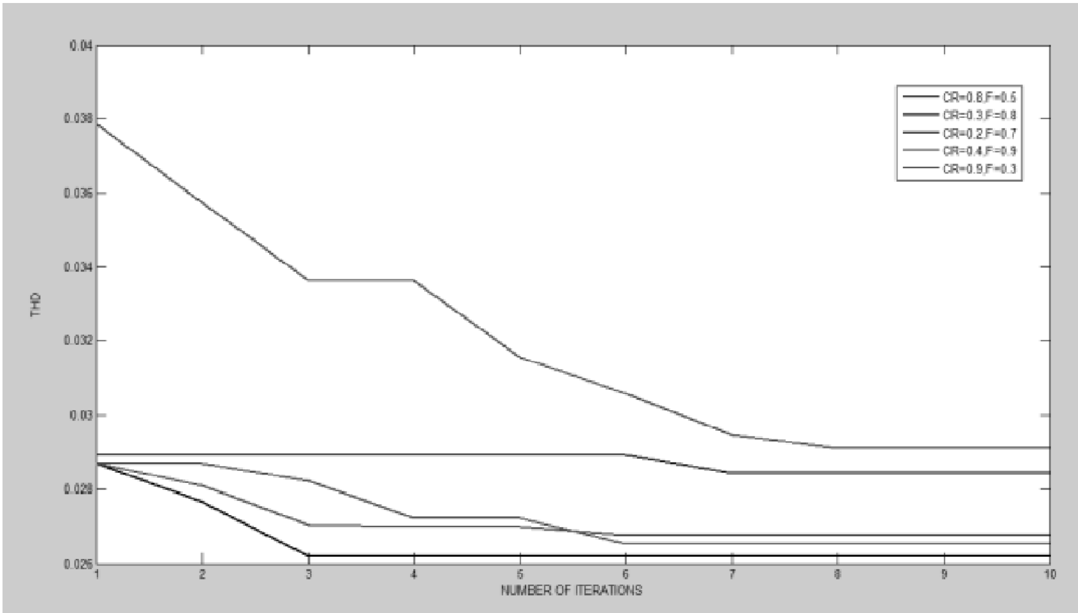

Figure 9: Optimal convergence graph of source current

Fig. 9 shows different plots for various C_r(cross over) and F(mutation) values. For ten iterations for C_R =0.3;F=0.8 values and by taking objective function as F = F(THD of source current), The T.H.D has been reduced to 0.0262% as shown in fig. 10

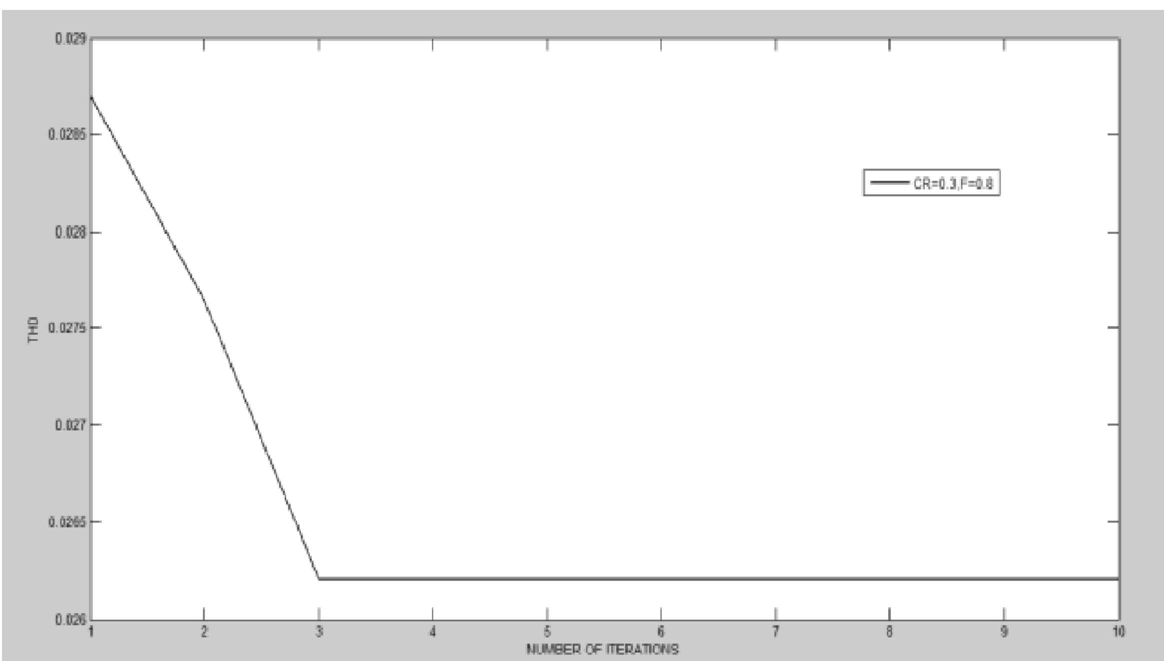

Figure 10: Optimal convergence graph of source current for CR = 0.3; F = 0.8

Table 1
Performance Results For Various CR (Cross Over) and F (Mutation) Values

Cr	*F*	*Kp*	*Ki*	*THD*
0.8	0.5	0.0265	19.7315	0.0265
0.2	0.7	9.8263	8.2332	0.0284
0.9	0.3	7.8936	18.8548	0.0291
0.4	0.9	10	14.0989	0.0267
0.3	0.8	10	17.2706	0.0262

The above table shows THD values and K_{p}, K_{i} values for different cross over (C_r) and Mutation (F) values.

Table II
Comparison of Performance Results for with Out Pq Theory, with Pq Theory and Pq Theory with Differential Evolution Technique

Without PQ theory	18.72% (THD)
With PQ theory	7.46% (THD)
PQ-DE	4.83% (THD)

Above table shows minimum Total Harmonic Distortion value with combination of PQ-DE. So, PI controller optimized with DE technique shows less THD value when compared to normal PI-controller.

5. CONCLUSION

In this study, Differential evolution technique is proposed to modify the current harmonics and enhances power quality. Through usage of instantaneous real as well as reactive power (p-q) theory with PI controller for controlling the HBCC based shunt active filter, that is utilized for compensating the current harmonics. A comparative analysis has been made between distribution line with nonlinear load, PQ theory applied with PI controller, PQ theory optimized with DE technique (PQ-DE). The results shows that the THD levels are decreased by using DE technique with different Cross over and Mutation values are found to be accurate. Here PQ theory optimized with DE shows better results when compared with normal PQ theory with PI controller.

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